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TO: Mr. R. Coutts
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A STUDY OF THE REPRESENTATIVENESS OF THE BNPD 100-m METEOROLOGICAL TOWER

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ABSTRACT

The representativeness of the wind direction and wind speed measured at the 10-m level of the BNPD Tower was investigated by comparing results from this site to measurements made elsewhere during a 1-year Research Division study. The analysis indicates that the wind direction measured at the BNPD Tower is not representative of the primary zone. The wind speed measurements at the Tower do *not* accurately represent conditions below the bluff, however they are representative of conditions on the bluff.

INTRODUCTION

A strategy for on-site meteorological monitoring at Ontario Hydro nuclear generating stations, for nuclear emergency response, has been defined/1/. Among other things, this strategy states that:

- instrumentation to measure wind speed, wind direction, wind shear in the lower atmosphere at lakeshore sites, ambient air temperature and atmospheric turbulent diffusion be located at each site; and

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- the instrumentation be sited so that measurements are representative of the atmospheric conditions experienced by the emissions moving inland.

Implementation of this strategy is underway. One of the steps in this process involves evaluating existing instrumentation at each site for representativeness. The representativeness of the BNPD 100-m meteorological tower is the subject of this report.

BNPD is located on the east shore of Lake Huron (Figure 1). The coastline is very irregular at the site and it is not possible to define directions at right angles and parallel to the shore. The land is forested within a mile of the lake; farther inland the countryside is open farmland. A notable feature is the sharp rise in elevation (about 30 m) 3-5 km from the lake.

The BNPD 100-m meteorological tower is located at MacPherson Point, near the lakeshore. The tower is instrumented with anemometers at the 10-, 30- and 100-m levels and with temperature sensors at the 10-, 50- and 100-m levels.

REPRESENTATIVENESS

For our purposes, representativeness will be defined as the extent to which measurements taken at a point (ie, the BNPD Tower) represent conditions elsewhere (ie, at the point of emission and throughout the 10-km radius primary zone). It will be further assumed that measurements are representative if there is a high probability that the point measurements lie within a given range of the areal mean.

The areal mean is seldom known in practice but rather must be estimated from simultaneous measurements made within the zone of interest. We must then proceed in one of two ways, carry out a number of paired comparisons between the various data sets, or derive the mean of the measurements and then compare this against the point measurement we want to test for representativeness. The first approach will be used here.

To see how the paired comparison test is applied, let's assume that

W_{di}^{T} is the ith hourly wind direction measured at the BNPD Tower, and

W_{di}^{S} is the ith hourly wind direction measured at another site.

The paired differences W_{di}^{T-S} given by:

$$W_{di}^{T-S} = W_{di}^{T} - W_{di}^{S}$$

are then calculated and the distribution of W_{di}^{T-S} examined for its mean, standard deviation, etc.

At BNPD, we had two sets of measurements made during July 1984 - June 1985 by Research Division, one near the Bruce 'A' Switchyard, the other at the Visitors' Centre on top of the bluff. These are identified as A and B, respectively in Figure 1. The Research Division

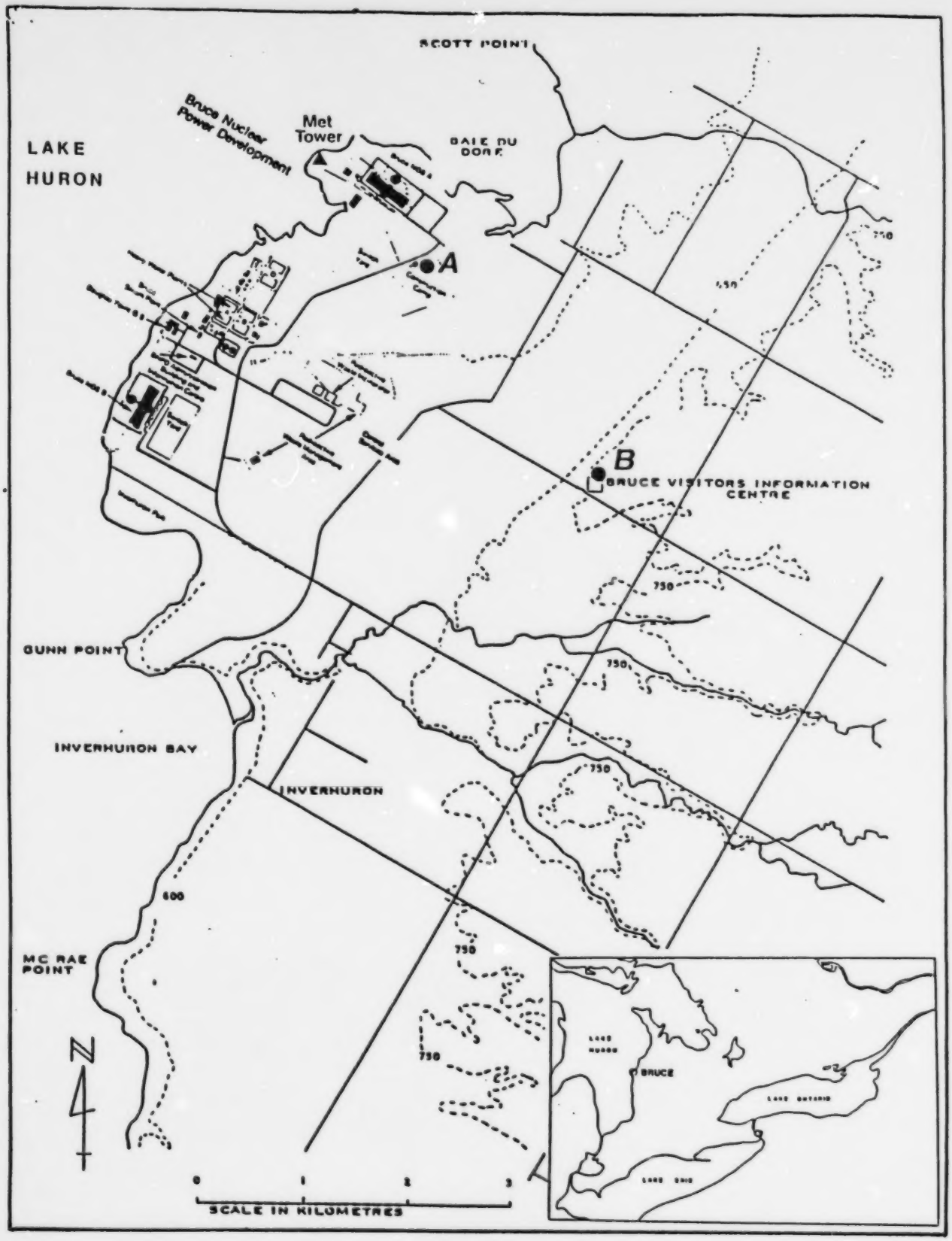


FIGURE 1

The Vicinity of Bruce Nuclear Power Development

study looked at wind direction and speed at 10 m above ground, temperature and solar radiation at about 1.5 m above ground, as well as the structure of the lower atmosphere, the latter using acoustic sounders.

It is apparent that not all the meteorological measurements made at the BNPD Tower can be tested for representativeness with the data available from the Research Division study. In fact, only the wind direction and wind speed at the 10-m level will be examined in this report.

THE DATA BASE

Wind speed and direction measured at the 10-m level at the BNPD Tower and the Research Division Switchyard and Visitors' Centre sites were obtained, screened for obvious errors and combined to produce the following sets of paired hourly values:

- BNPD Tower vs Switchyard 5,258
- BNPD Tower vs Visitors' Centre 5,429
- Switchyard vs Visitors' Centre 4,224

The data actually used in the analysis was further reduced by eliminating very low wind speed cases (ie, near or below the starting threshold of the anemometers, 2 m s^{-1}) and considering only onshore flows. (Analyses based on the onshore and offshore data combined are given in Appendix A). The fraction of the data eliminated as being below the anemometer threshold was 16%, 10% and 17% between the BNPD Tower and Switchyard, the BNPD Tower and Visitors' Centre and the Switchyard and Visitors' Centre, respectively.

REPRESENTATIVENESS OF WIND DIRECTION

Scatter plots of the three sets of wind direction measurements are shown in Figure 2. Figure 3 shows histograms of the paired differences for the three sets of measurements. The mean and standard deviation of the paired differences are summarized below.

	Mean	Standard Deviation
BNPD Tower - Switchyard	13.3°	20.0°
BNPD Tower - Visitors' Centre	17.3°	28.5°
Switchyard - Visitors' Centre	8.3°	24.8°

We see that the winds turn countercloskwise 13.3° on average as they move from the lakeshore to the Switchyard and a further few degrees (ie, 17.3°-13.3° = 4.0° if the BNPD Tower, Switchyard and Visitors' Centre data are used or 8.3° if only the Switchyard and Visitors' Centre data are compared) as they move past the bluff. As discussed in Appendix B, this turning of the wind is expected and is due to the higher roughness of the land relative to the lake surface.

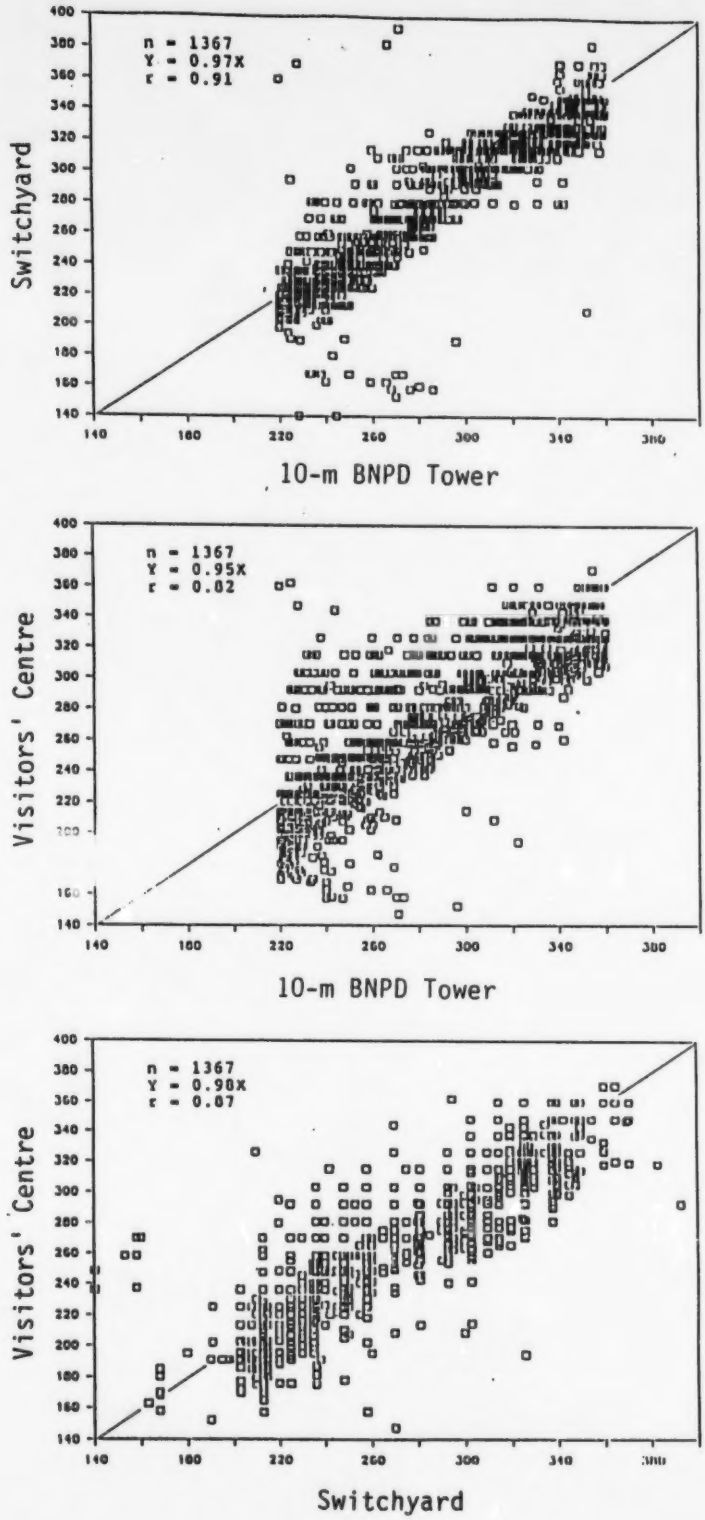


FIGURE 2

SCATTER PLOTS OF WIND DIRECTION (DEGREES)
ONSHORE FLOWS ONLY

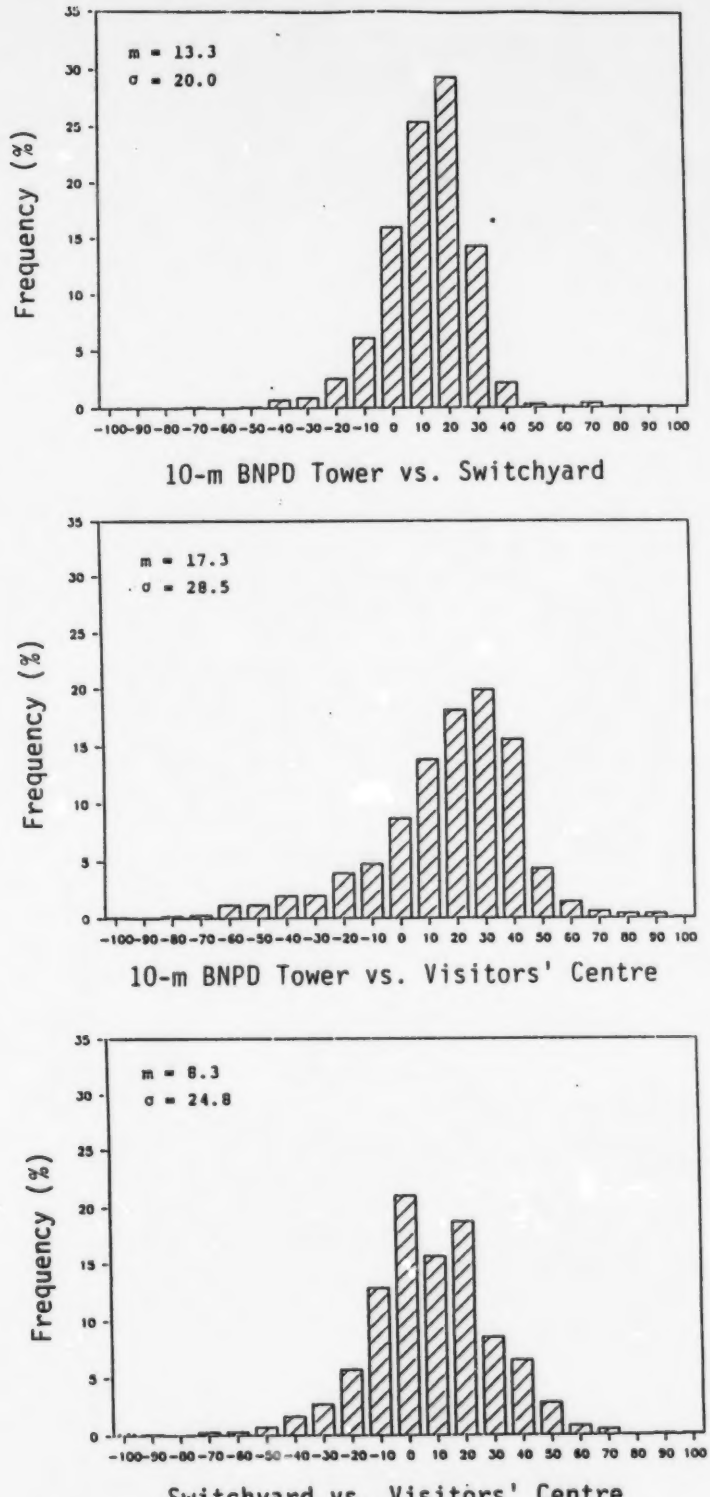


FIGURE 3

HISTOGRAMS OF PAIRED WIND DIRECTION DIFFERENCES (DEGREES)
ONSHORE FLOWS ONLY

Returning now to the question of representativeness, if we specify a requirement that 90% of all pairs of measurements agree to within ±15° (the range of 30° is equal to the average size of the emergency response sectors) we conclude that none of the three sets of measurements satisfies this requirement. In fact, the fraction of measurements agreeing to within ±15° is as follows:

	Fraction of Values Agreeing to Within ±15°
BNPD Tower vs Switchyard	47%
BNPD Tower vs Visitors' Centre	27%
Switchyard vs Visitors' Centre	50%

REPRESENTATIVENESS OF WIND SPEED

Scatter diagrams of the three sets of wind speed measurements are shown in Figure 4. Figure 5 shows histograms of the paired differences for the three sets of measurements. The mean and standard deviation of the paired differences (in km/h) are summarized below.

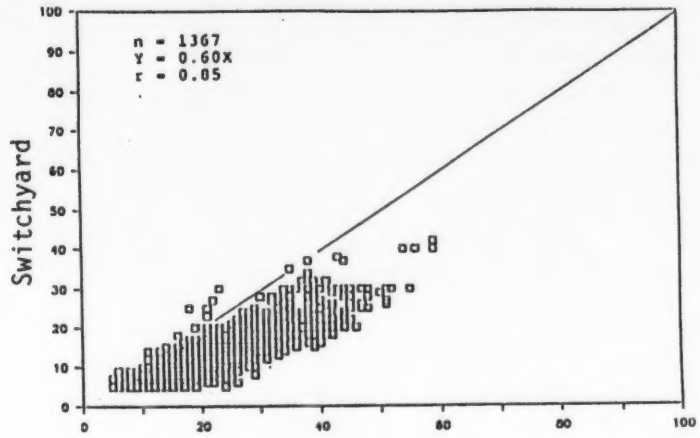
	Mean	Standard Deviation
BNPD Tower - Switchyard	8.3	5.1
BNPD Tower - Visitors' Centre	4.9	5.7
Switchyard - Visitors' Centre	-3.4	4.2

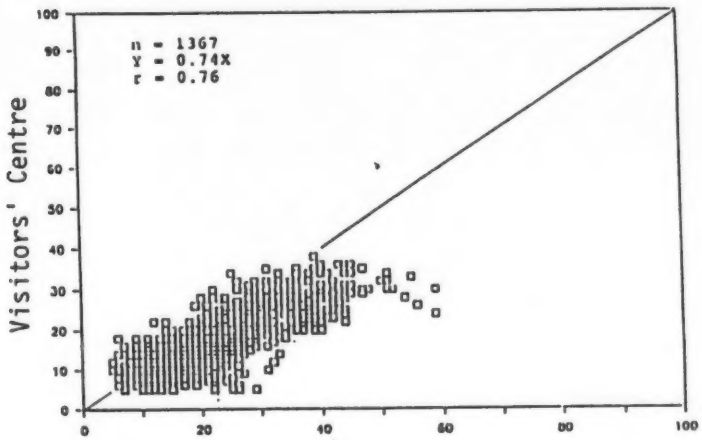
It is apparent that onshore flows are fastest at the lakeshore. The winds slow down 8.3 km/h on average as they travel over the rougher land surface, to the Switchyard site. The analysis further suggests that the winds then speed up by about 3.4 km/h as they flow over the bluff. These differences are consistent with the well-known behaviour of atmospheric flows near the earth's surface, see Appendix B.

The question of representativeness will be considered with reference to the dispersion models used for nuclear emergency response. The concentrations predicted by these models depend on the inverse of the wind speed. That is:

$$C = f/W, \qquad (1)$$

where C is the concentration, W, the wind speed and f a factor which depends on downwind distance and atmospheric stability. (The dependence of f on W, will be ignored here).





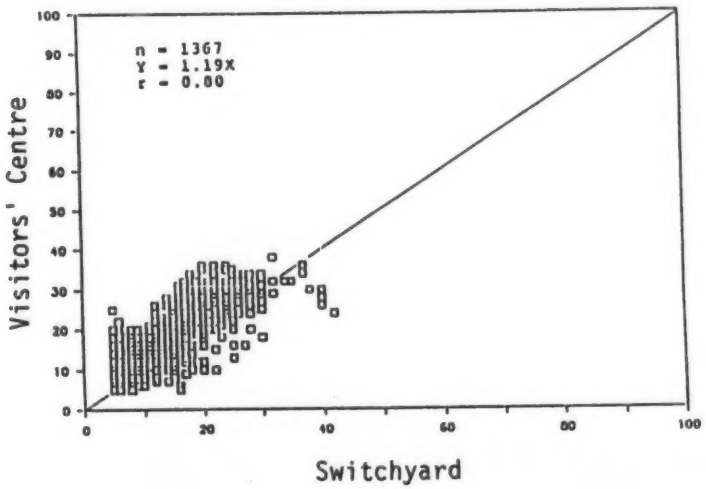
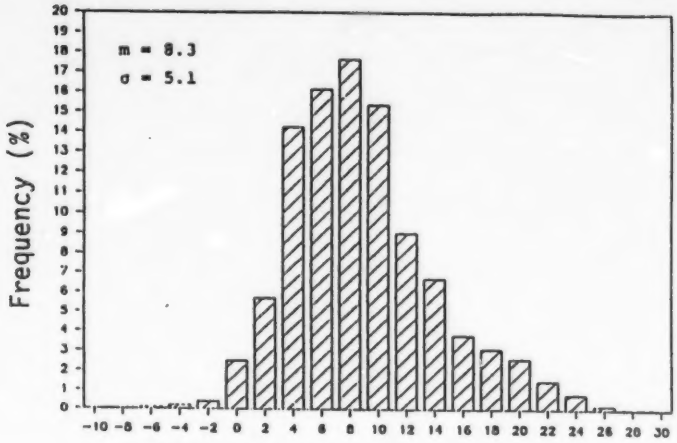
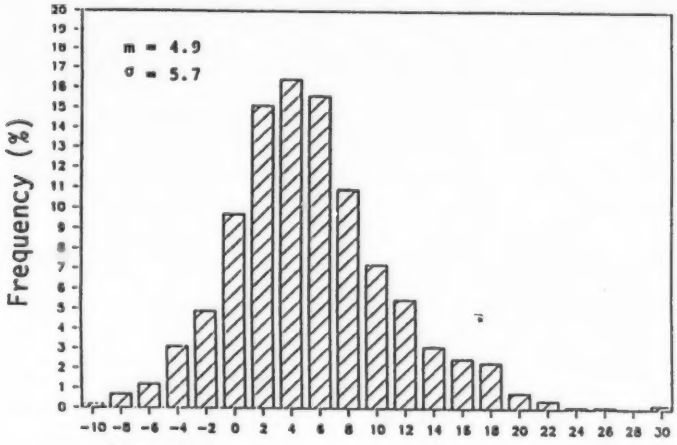


FIGURE 4
SCATTER PLOTS OF WIND SPEED (KM/H)
ONSHORE FLOWS ONLY





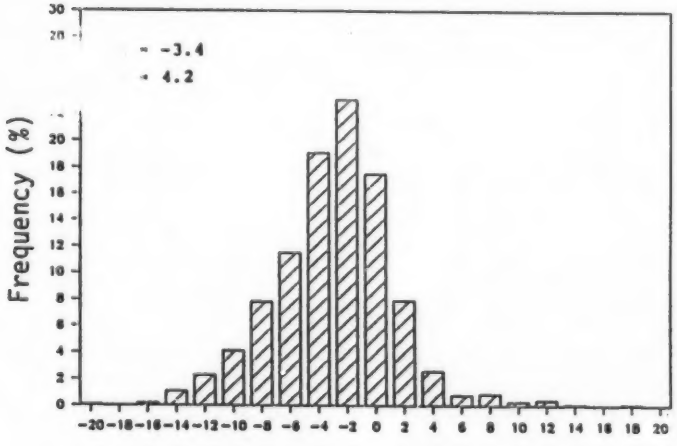


FIGURE 5
HISTOGRAMS OF PAIRED WIND SPEED DIFFERENCES (KM/H)
ONSHORE FLOWS ONLY

The sensitivity of C to W_s can be examined by comparing the predictions of (1) with the true (denoted by superscript o) and approximate values of W_s, ie, from (1)

$$C/C^o = W_s^o/W_s \qquad (2)$$

If we tolerate a factor of 2 error in C, equation (2) indicates that W_s needs to be known to within a factor of 2. We will then consider wind speed measurements to be representative if they agree to within a factor of 2, at least 90% of the time.

When this definition of representativeness is applied to the BNPD data, the following results are obtained:

	Fraction of Values Agreeing to Within a Factor of Two*	
BNPD Tower vs Switchyard	83%	(78%)
BNPD Tower vs Visitors' Centre	93%	(89%)
Switchyard vs Visitors' Centre	95%	(95%)

CONCLUSIONS

An attempt was made to determine the representativeness of the BNPD Tower. Of the meteorological measurements needed for nuclear emergency response (ie, wind speed, wind direction, wind shear in the lower atmosphere at lakeshore sites, ambient air temperature and atmosphere turbulent diffusion), only the wind direction and wind speed measured at the 10-m level on the Tower could be evaluated because of constrains in comparative data and time. The comparative data came from a Research Division study in 1984-85 in which measurements were made at a site between the lakeshore and the bluff and another on top of the bluff.

For the purposes of the study, it was assumed that wind direction measurements are representative if they agree with measurements made elsewhere in the primary zone to within ±15°, at least 90% of the time. For onshore flows, this criterion is not met at BNPD; the agreement is only 27-50%. This conclusion is the same when the analysis is based on the onshore and offshore flows, combined.

*The first set of percentages was calculated using the wind speed measured at the site listed first as the reference value (eg, BNPD Tower in the BNPD Tower-Switchyard pair.) The values in brackets were calculated by taking the second station as the reference.

Wind speeds were assumed to be representative if they agree with measurements made elsewhere in the primary zone to within a factor of 2, at least 90% of the time. The Switchyard site was found to be representative of wind speeds above the bluff. The BNPD tower was also representative of conditions above the bluff; but exhibited a slightly poorer correlation. However, below the bluff the agreement between the BNPD Tower and the Switchyard site was 78% or 83%, depending on which site was taken as reference, and the criterion of representativeness was not met.

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APPENDIX A

REPRESENTATIVENESS BASED ON THE ONSHORE AND OFFSHORE FLOWS COMBINED

Wind Direction

Scatter plots of the three sets of wind direction measurements are shown in Figure A1. Figure A2 shows histograms of the paired differences for the three sets of measurements. The mean and standard deviation of the paired differences are summarized below.

	Mean	Standard Deviation
BNPD Tower - Switchyard	16.2°	16.9°
BNPD Tower - Visitors' Centre	19.4°	37.7°
Switchyard - Visitors' Centre	-1.5°	22.9°

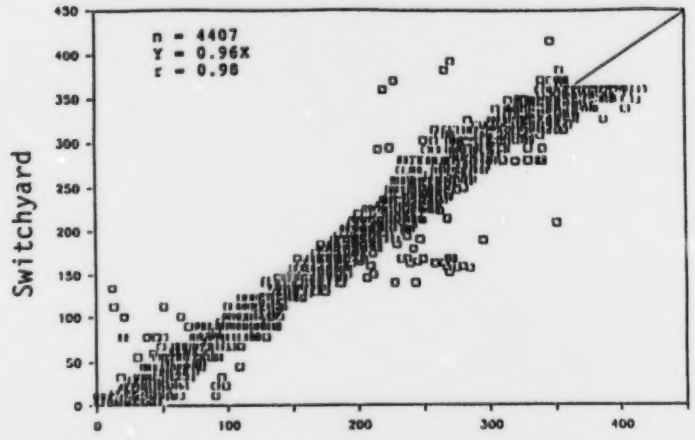
The fraction of measurements agreeing to within ±15° is as follows.

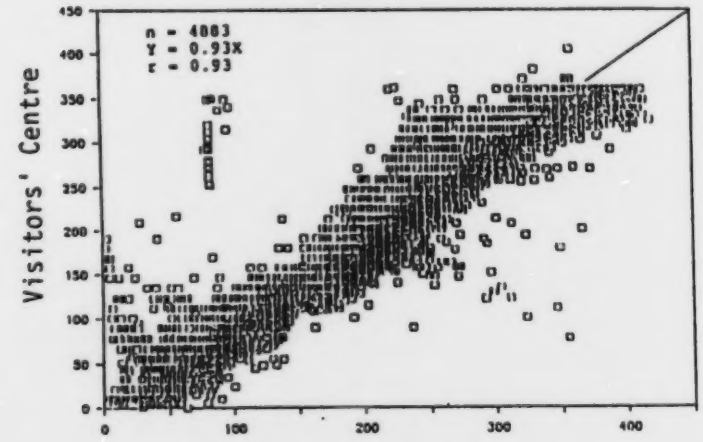
	Fraction of Values Agreeing to Within ±15°
BNPD Tower vs Switchyard	39%
BNPD Tower vs Visitors' Centre	22%
Switchyard vs Visitors' Centre	53%

Wind Speed

Scatter plots of the three sets of wind speed measurements are shown in Figure A3. Figure A4 shows histograms of the paired differences for the three sets of measurements. The mean and standard deviation of the paired differences (in km/h) are summarized below.

	Mean	Standard Deviation
BNPD Tower - Switchyard	7.4	4.7
BNPD Tower - Visitors' Centre	2.1	6.8
Switchyard - Visitors' Centre	4.9	5.5





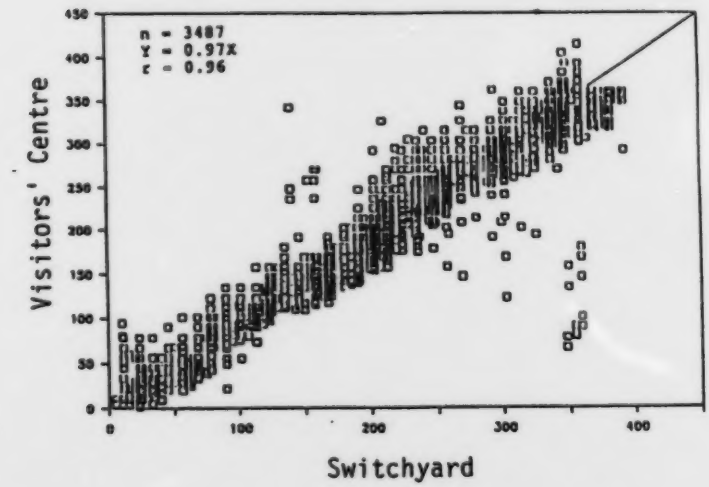
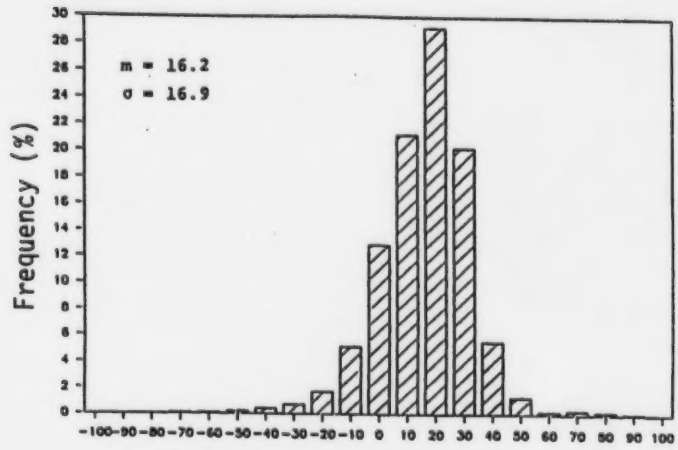
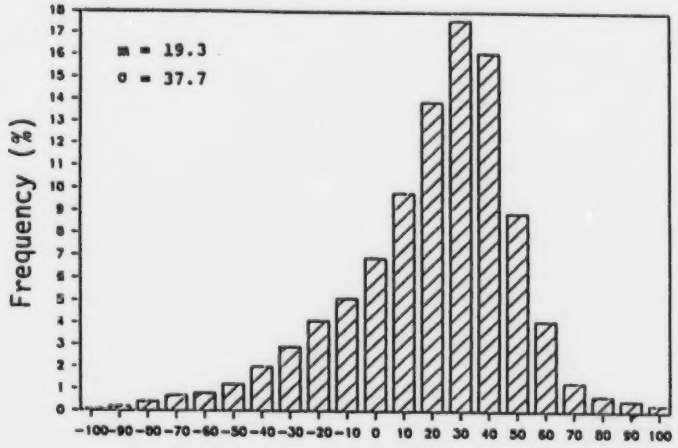


FIGURE A1

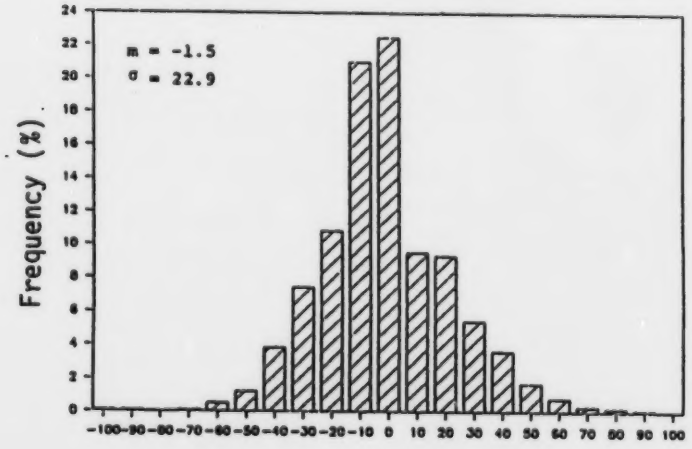
SCATTER PLOTS OF WIND DIRECTION (DEGREES) ONSHORE AND OFFSHORE FLOWS COMBINED



10-m BNPD Tower vs. Switchyard

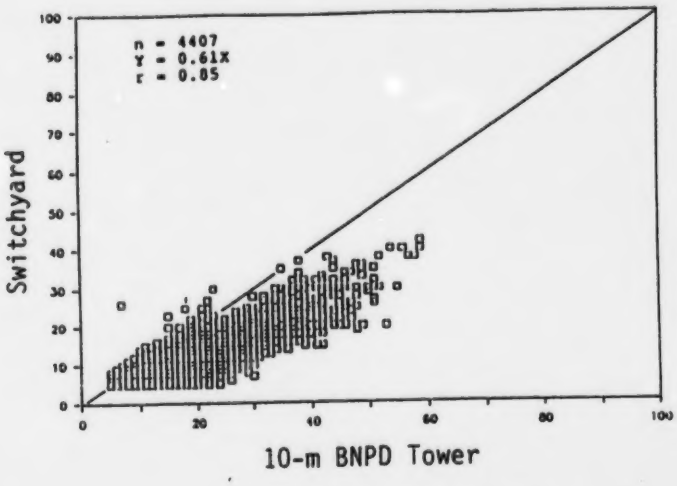


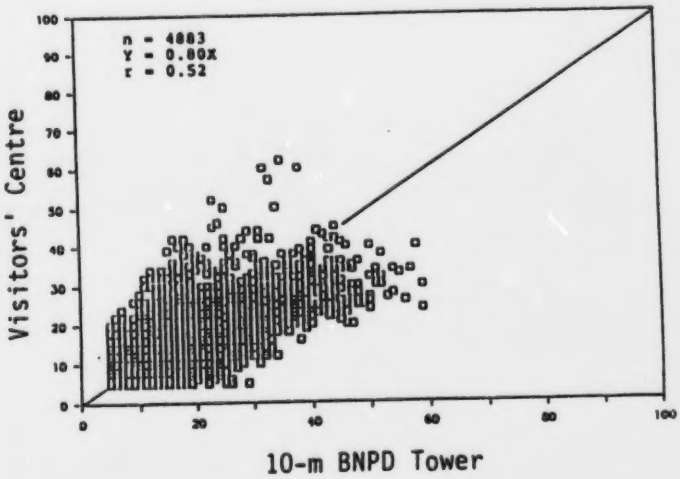
10-m BNPD Tower vs. Visitors' Centre



Switchyard vs. Visitors' Centre

FIGURE A2
HISTOGRAMS OF PAIRED WIND DIRECTION DIFFERENCES (DEGREES) ONSHORE AND OFFSHORE FLOWS COMBINED





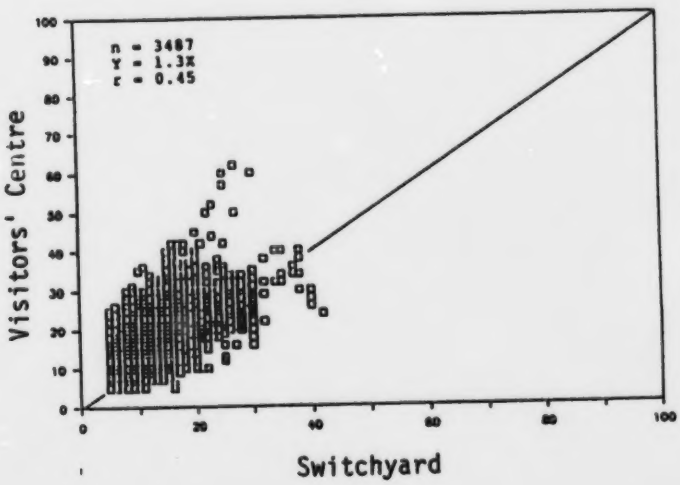
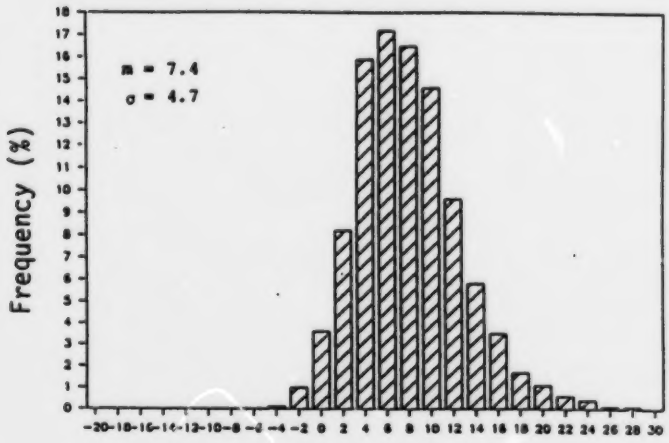
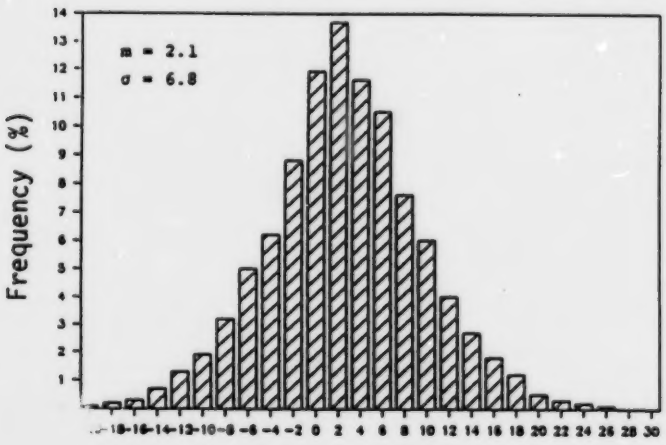


FIGURE A3

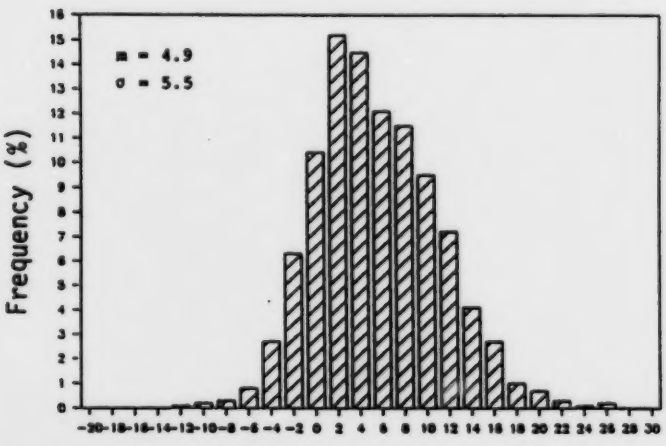
SCATTER PLOTS OF WIND SPEED (KM/H)
ONSHORE AND OFFSHORE FLOWS COMBINED



10-m BNPD Tower vs. Switchyard



10-m BNPD Tower vs. Visitors' Centre



Switchyard vs. Visitors' Centre

FIGURE A4

HISTOGRAMS OF PAIRED WIND SPEED DIFFERENCES (KM/H)
ONSHORE AND OFFSHORE FLOWS COMBINED

The fraction of measurements agreeing to within a factor of 2 is as follows.

	Fraction of Values Agreeing to Within a Factor of Two	
BNPD Tower vs Switchyard	85%	(80%)
BNPD Tower vs Visitors' Centre	89%	(87%)
Switchyard vs Visitors' Centre	61%	(63%)

APPENDIX B

ATMOSPHERIC FLOW NEAR THE GROUND

Atmospheric flow is controlled by three forces - the horizontal pressure gradient force, the coriolis force and the frictional force. The frictional force is highly dependent on the properties of the underlying surface. The effect of the frictional force decreases with elevation. The region of the atmosphere extending from the earth's surface to the level where the frictional force becomes insignificant is called the planetary boundary layer. Above the planetary boundary layer the atmosphere is referred to as the geostrophic atmosphere or the free atmosphere. The air flow there is given by the geostrophic wind. A diagram showing these layers and their properties is shown in Figure B1/2/.

The atmospheric flow in the planetary boundary layer is quite complex. Large changes are observed from one height to another and from one horizontal location to another. Generally, the wind increases in speed and turns clockwise with elevation until it reaches the geostrophic wind velocity at the top. This pehnomenon is referred to as the Ekman spiral and is illutrated in Figure B2. Referring to the figure, the V vectors respresent the wind at various levels z. G is the asymptotic value where the wind is geostrophic V_g. The dashed vectors directed from G to each V represent the geostrophic deviation, which decreases with height and eventually vanishes at G. α_o is the cross-isobar angle at the surface and is a function of parameters such as surface roughness and atmospheric stability. A general relationship between α_o and these parameters is given in Table B1/3/. Normally α_o increases as the surface roughness and stability increase.

The rate at which wind speed increases with height is controlled by the frictional force imposed on the air by the underlying surface. As shown in Figure B3/4/, the rougher the surface the slower the increase in wind speed with elevation. This implies that the wind measured at a given level in the atmosphere, say 50 m above ground, will vary within short horizontal distances if abrupt changes in surface roughness are encountered (eg, lake-land interface).

The presence of hills or escarpments complicates the situation even further. A number of studies of air flow over hills and escarpments have been carried out in recent years/5-9/. In general the air flow accelerates on the upslope side, reaches a maximum over the top and decelerates on the downslope of the hill, see Figure B4. The extent to which the wind speeds up over the hill depends on the dimensions of the hill, H and L in Figure B4. In the Askervein Hill project, for example, speed-up factors of 1.6 were observed, see Figure B5.

Flow over a 90° escarpment has been studied both in the field and in a wind tunnel/9/. Typical results are shown in Figure B6. In this figure, the wind speed is given as relative values referenced to the upstream value 10 m above ground. A recirculation zone is observed at the base of the escarpment. On top of the escarpment, the air speeds up and a separation bubble can develop.

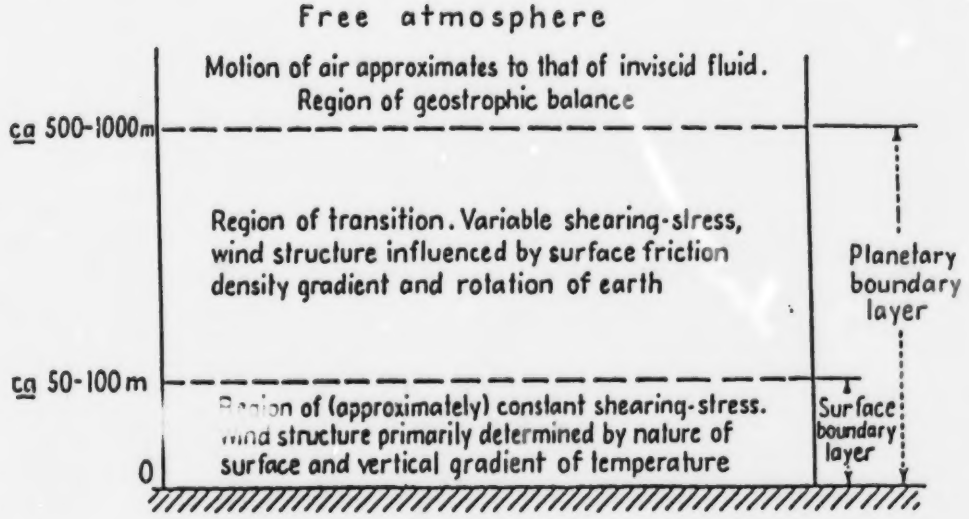


FIGURE B1
LAYERS OF THE LOWER ATMOSPHERE/2/

TABLE B.1 VALUES OF THE SURFACE CROSS-ISOBAR ANGLE/3/

Surface	Low latitudes (20°)			Middle latitudes (45°)			High latitudes (70°)		
	U	N	S	U	N	S	U	N	S
Ocean.....	25	30	40	15	20	30	10	15	25
Land (very smo... ...	35	40	50	25	30	40	20	25	35
Land (average).....	40	45	55	30	35	45	25	30	40
Land (rugged).....	45	50	60	35	40	50	30	40	45

U = unstable; N = neutral; S = stable.

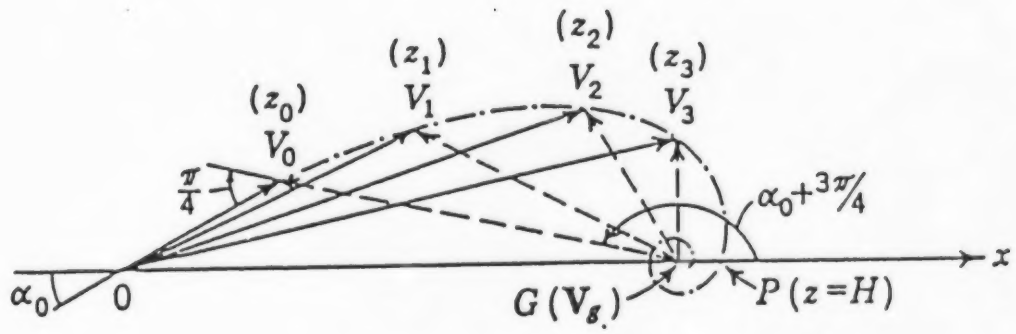


FIGURE B2
THE EKMAN SPIRAL

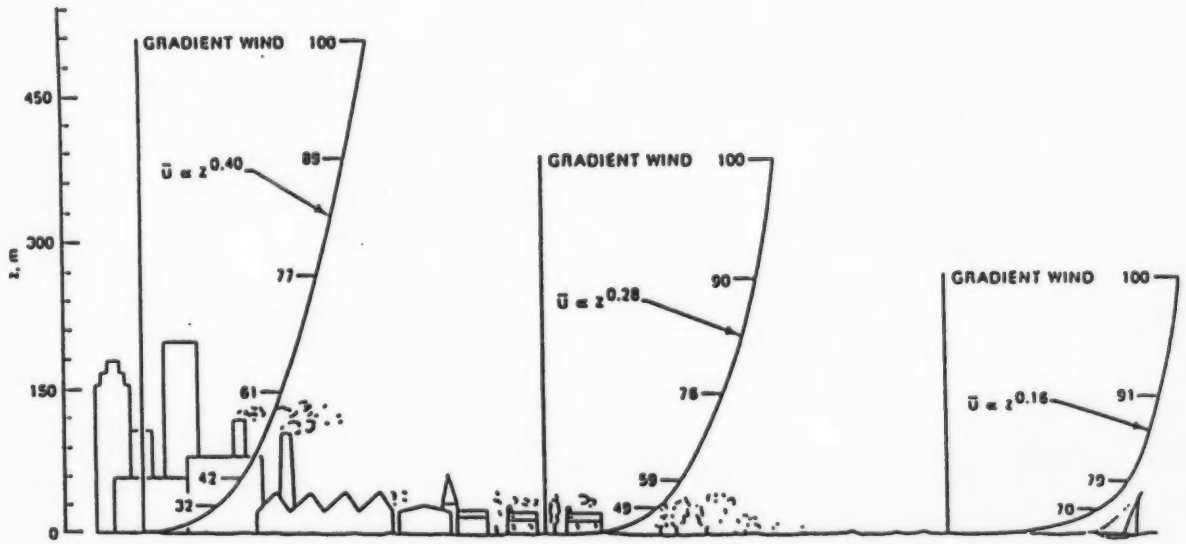


FIGURE B3
WIND SPEED PROFILES OVER SURFACES OF
DIFFERENT ROUGHNESS/4/

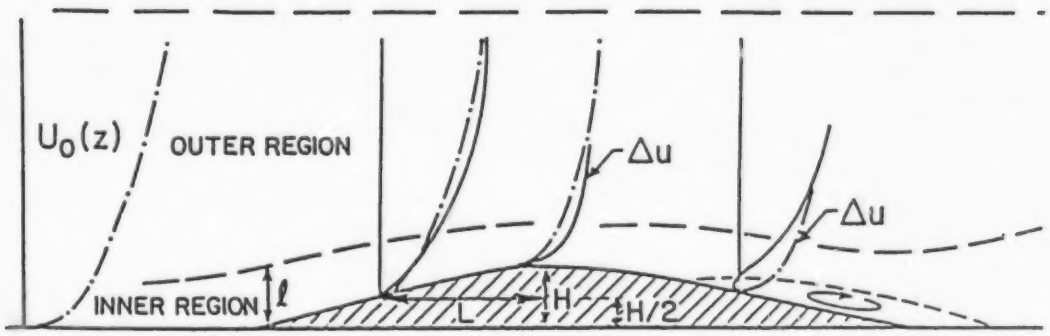


FIGURE B4
A CONCEPTUAL PICTURE OF WIND PROFILES OVER A HILL

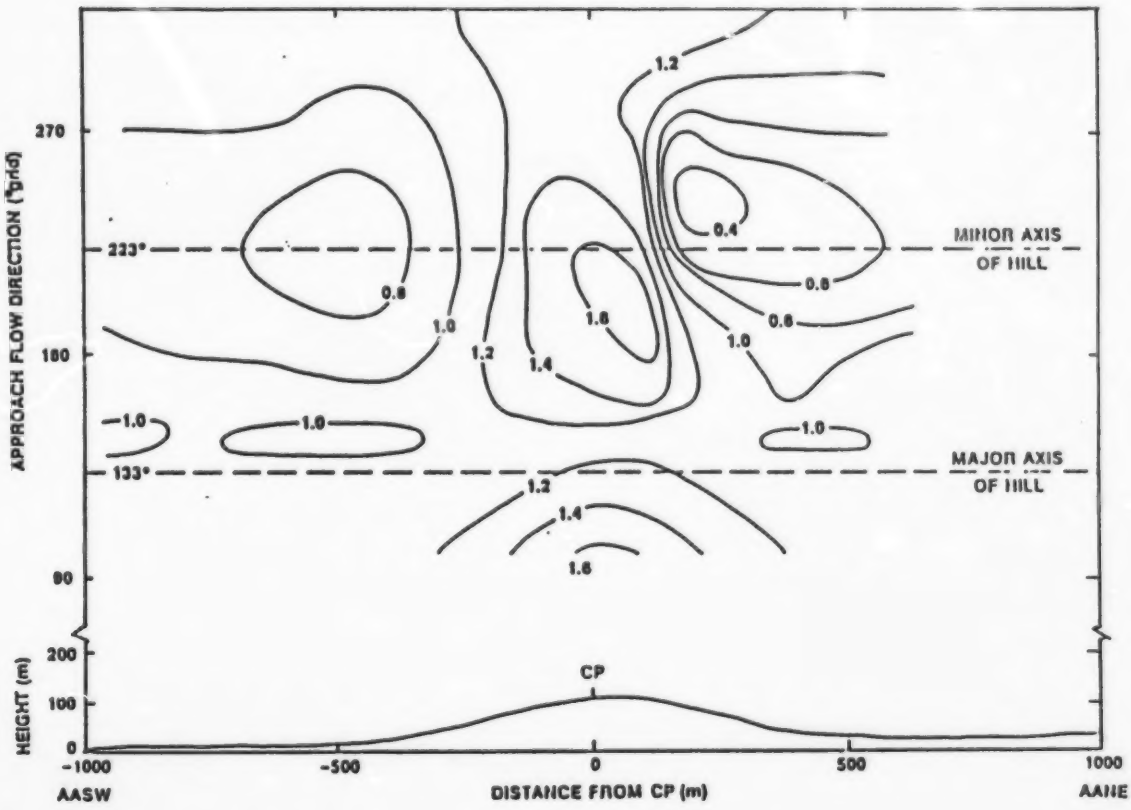


FIGURE B5
NORMALIZED WIND SPEED AT 10-m LEVEL FOR DIFFERENT WIND DIRECTIONS DURING THE 1983 ASKERVEIN HILL STUDY

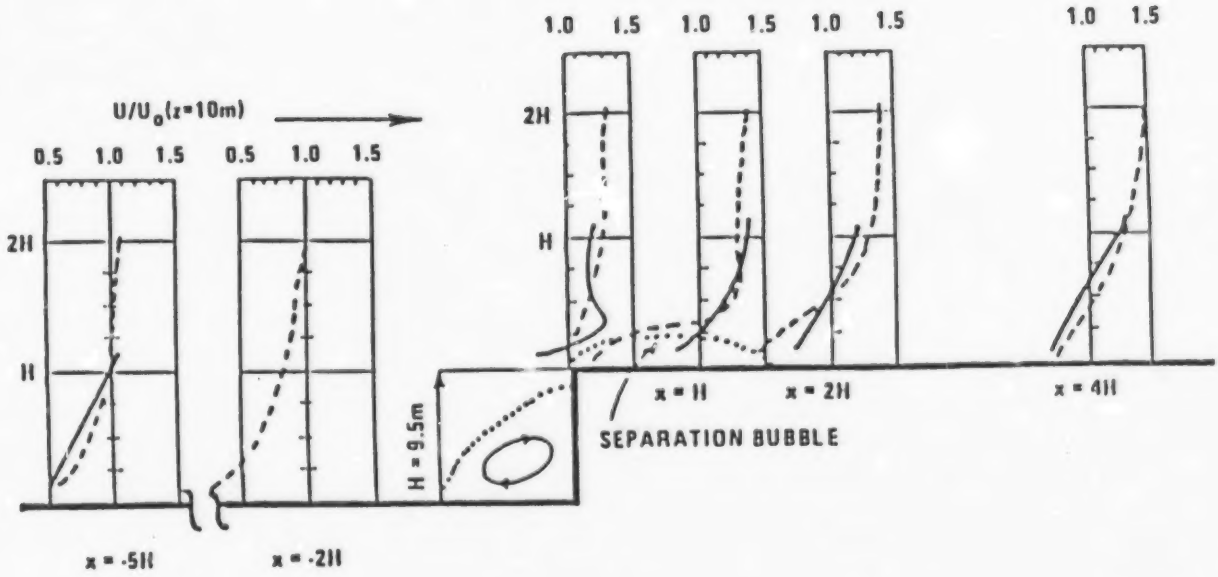


FIGURE B6

THE VARIATION OF MEAN WIND SPEED OVER A 90 DEGREE ESCARPMENT.
(THE SOLID LINES REPRESENT FIELD MEASUREMENTS WHILE
THE DASHED LINES REPRESENT WIND TUNNEL MEASUREMENTS)

The above description of atmospheric flows near the ground can be applied to the BNPD site. During onshore flows at BNPD, the increased roughness of the land surface relative to the lake surface will slow down the approaching wind and turn it counterlcockwise. The BNPD Tower measurements are, therefore, expected to show higher wind speeds and larger wind direction angles than, say, measurements at the Station Switchyard site.

As the air travels further inland, it will accelerate over the bluff. We should thus expect that the wind speed measured at the Visitors' Centre will be faster than that measured at the Station Switchyard site and closer to the measurements at the BNPD Tower. The winds will turn further counterclockwise as they proceed past the Visitor's Centre.